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Simulation of E-Cloud driven instability and its attenuation using a feedback system in the CERN SPS*

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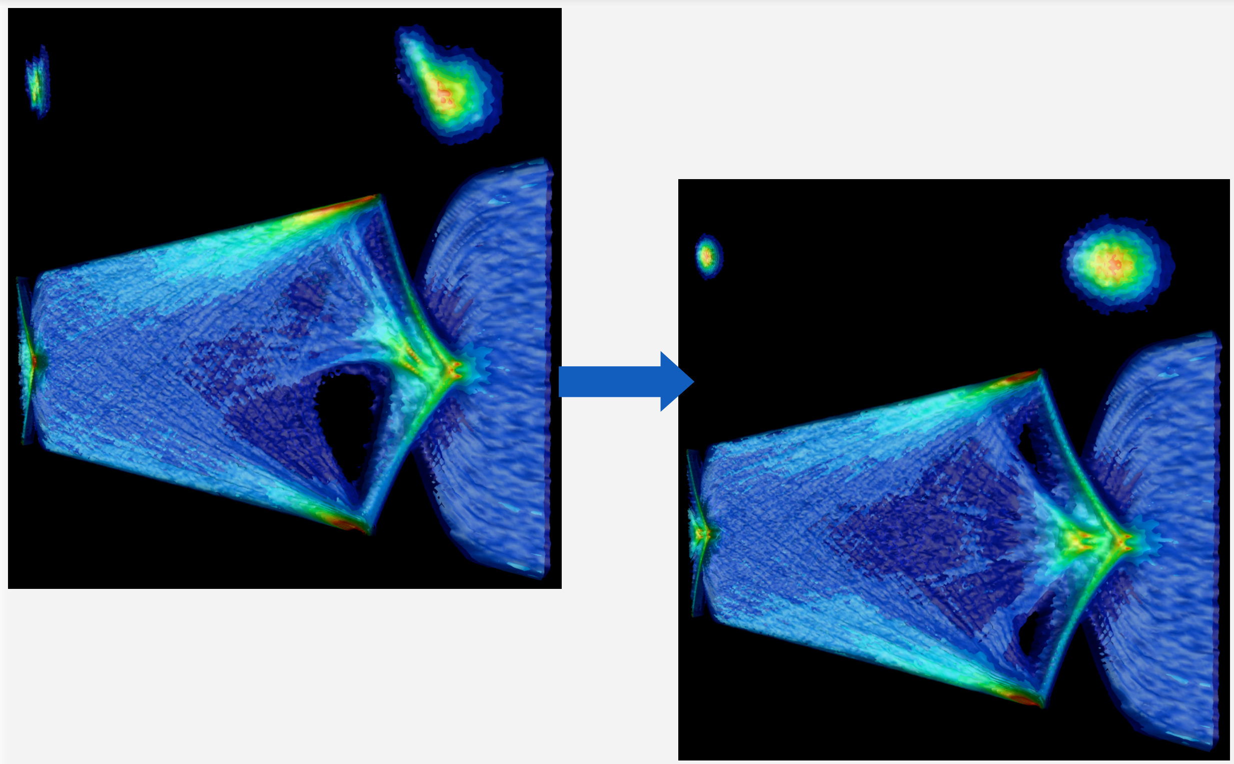
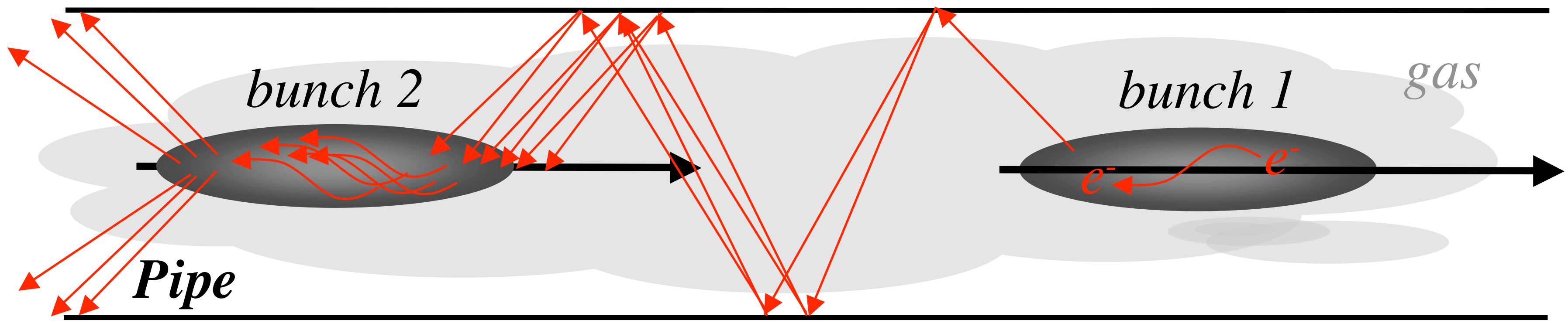


*WEOBRA02

The problem

- Transverse instability observed in SPS beams due to electron clouds

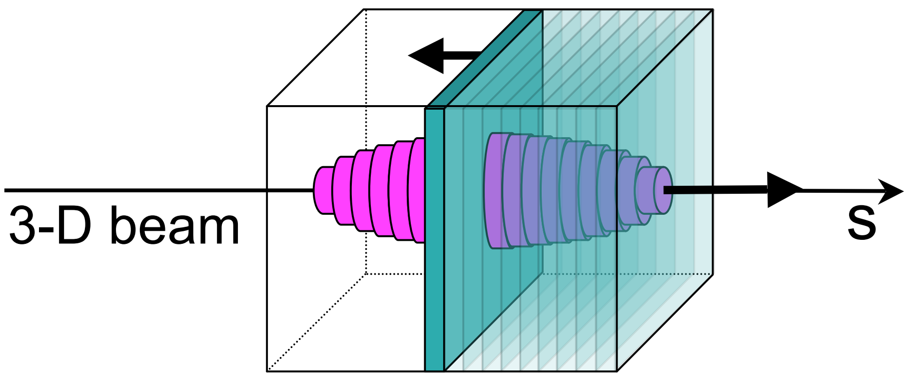


- Interaction between e-cloud and beam leads to large transverse oscillations
- Feedback system was proposed to control the beam transverse motion
- We use the Particle-In-Cell framework Warp-Posinst to investigate dynamics of instability as well as feasibility and requirements of feedback

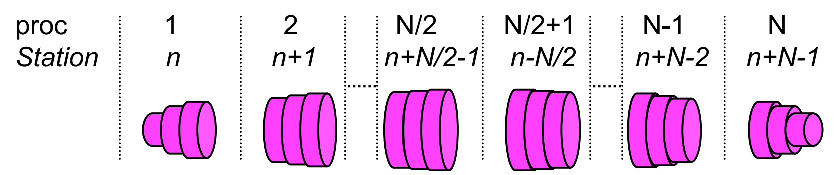
Our simulation framework encompasses the Warp and Posinst PIC codes

Warp quasistatic model similar to HEADTAIL, PEHTS, QuickPIC.

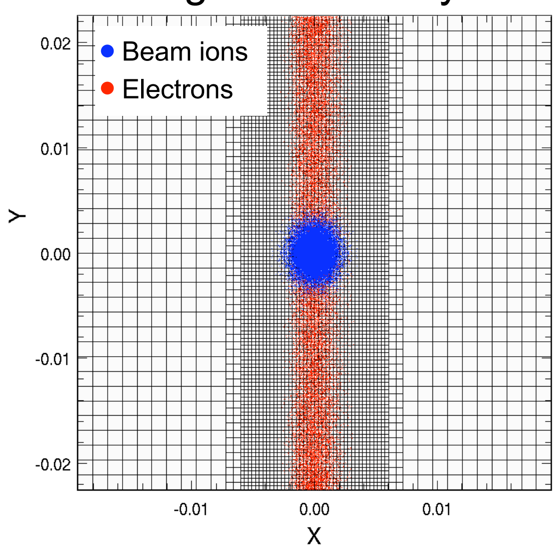
2-D slab of electrons



parallellized using pipelining



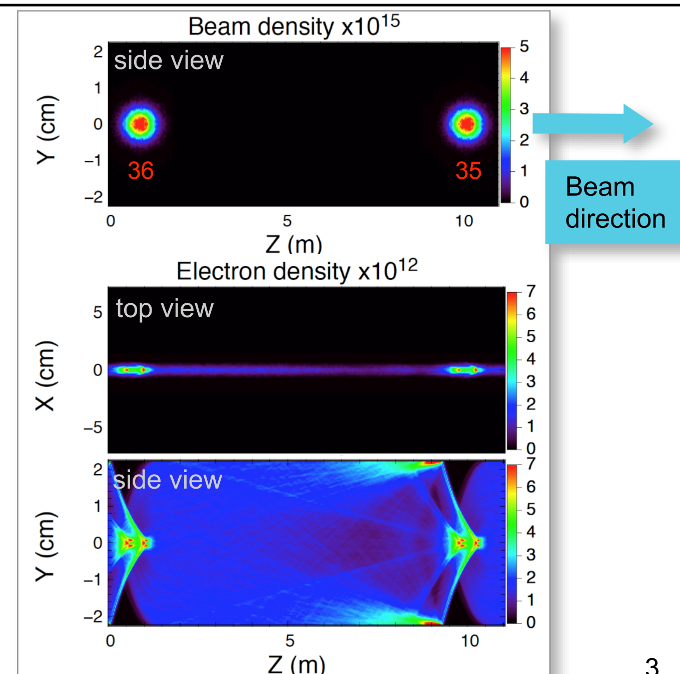
Mesh refinement provides higher efficiency



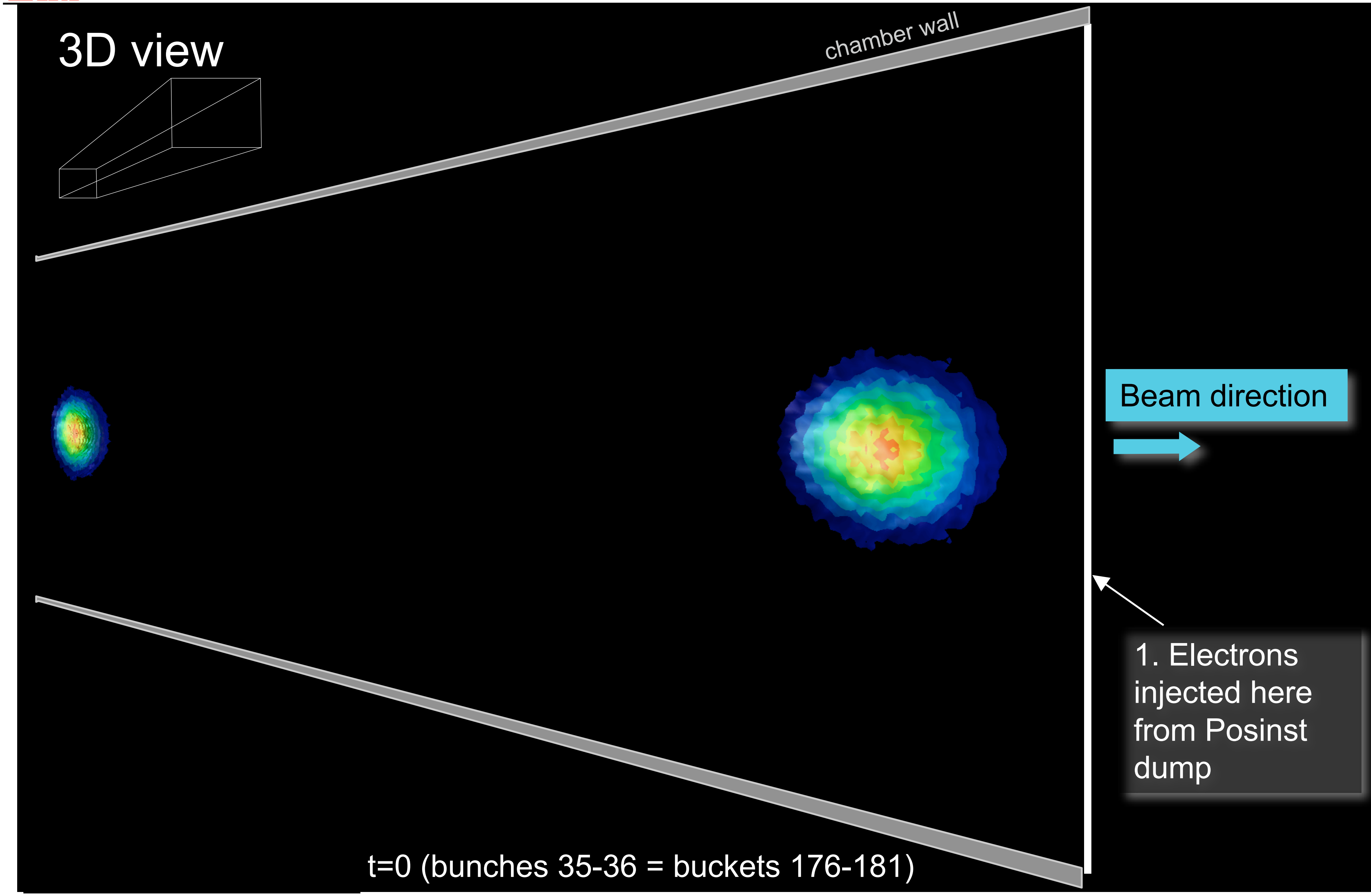
Secondary emission from Posinst:

- enables self-consistent multi-bunch calculations.

Example:
- 2 bunches separated by 25 ns in SPS



Physics of electron interaction with bunches



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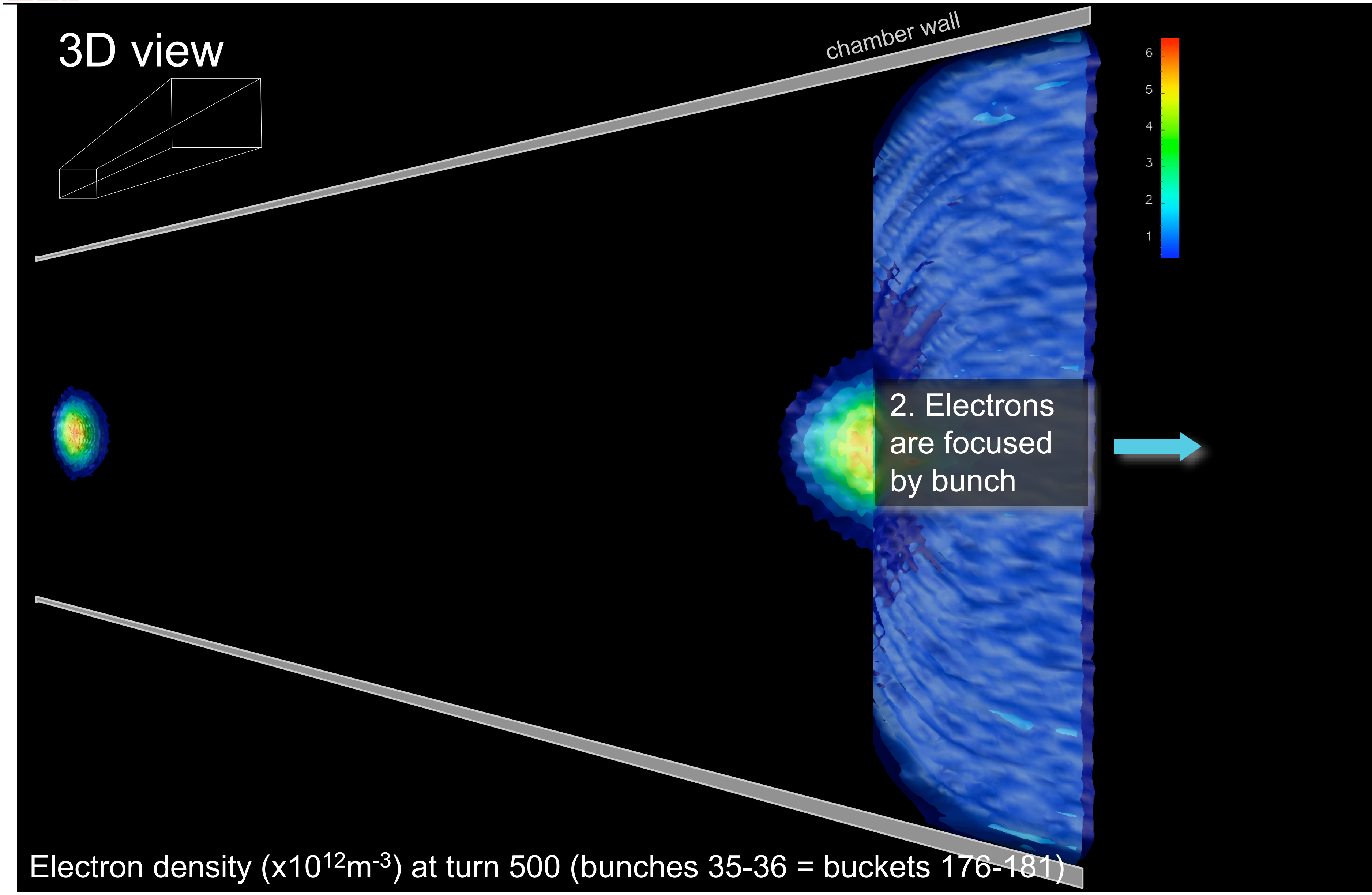
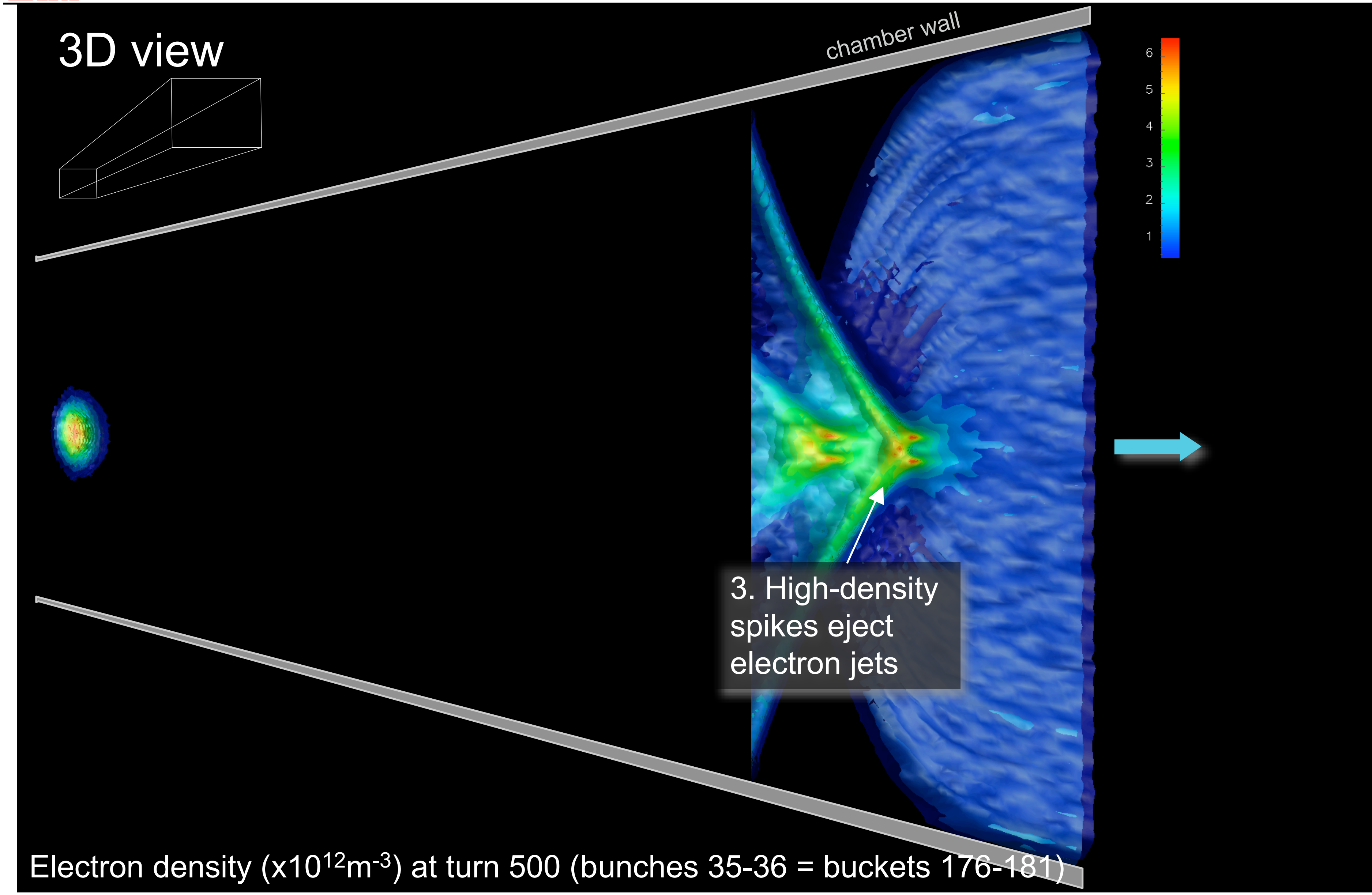
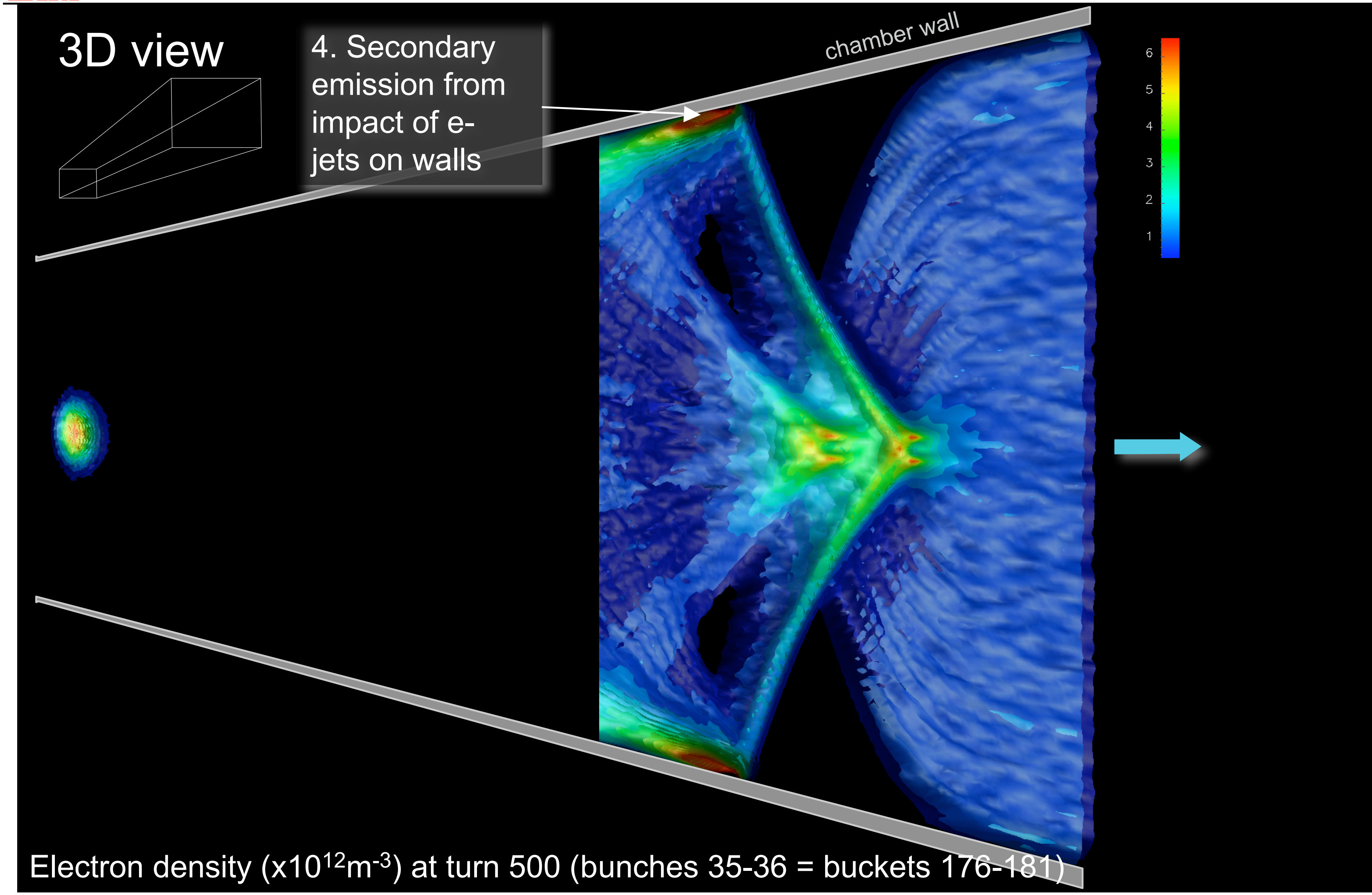


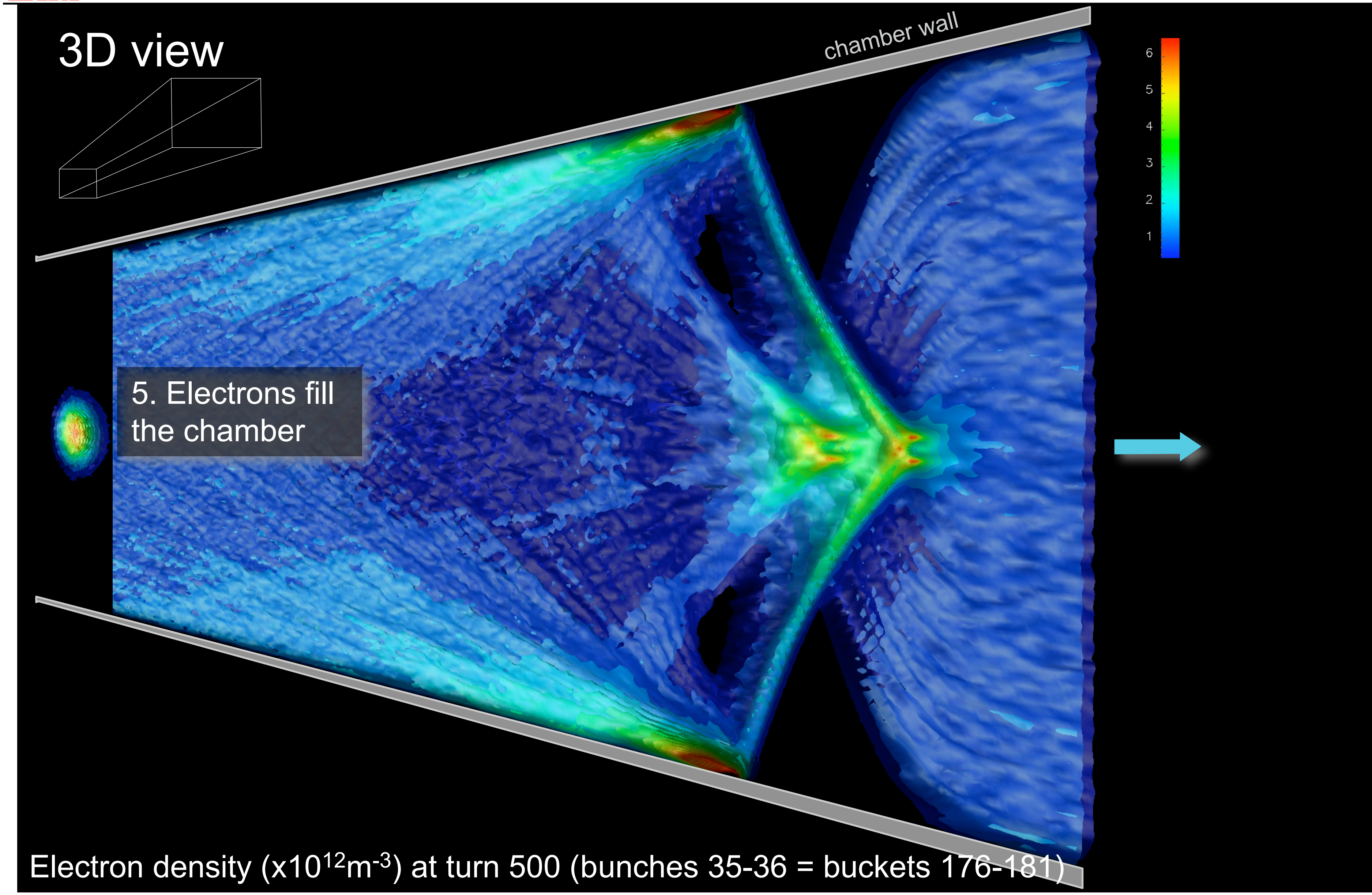
Physics of electron interaction with bunches



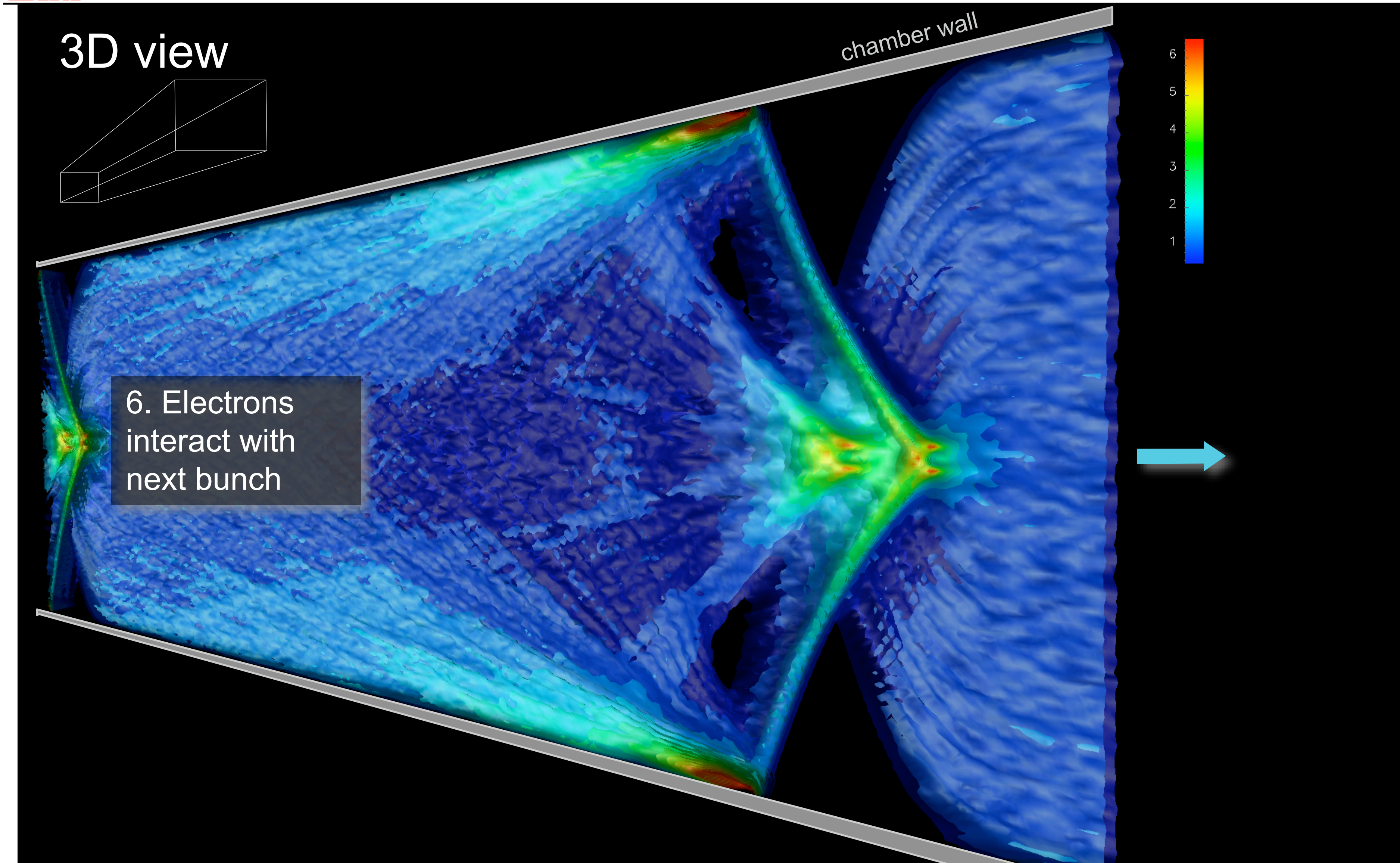
Physics of electron interaction with bunches



Physics of electron interaction with bunches

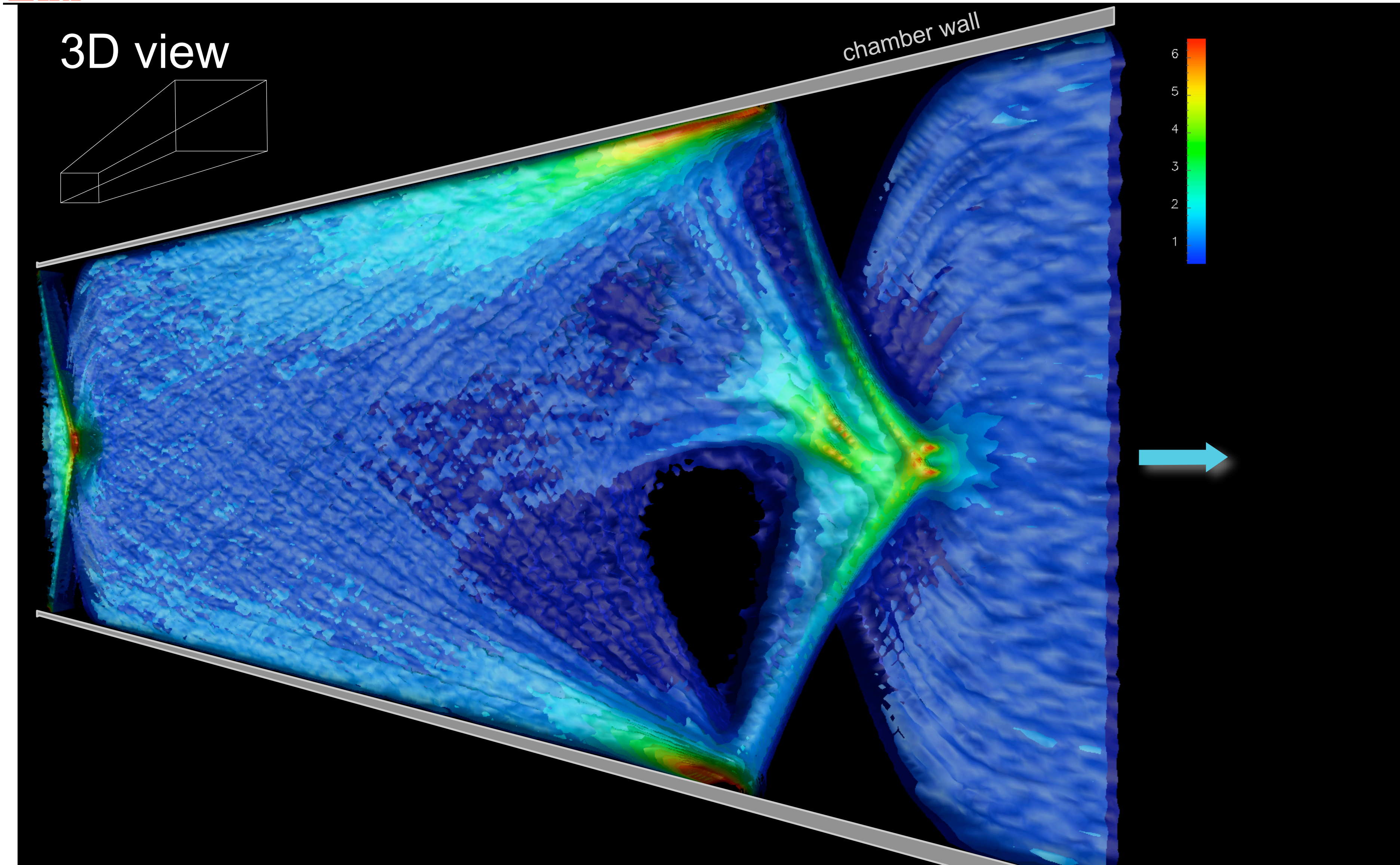


Physics of electron interaction with bunches



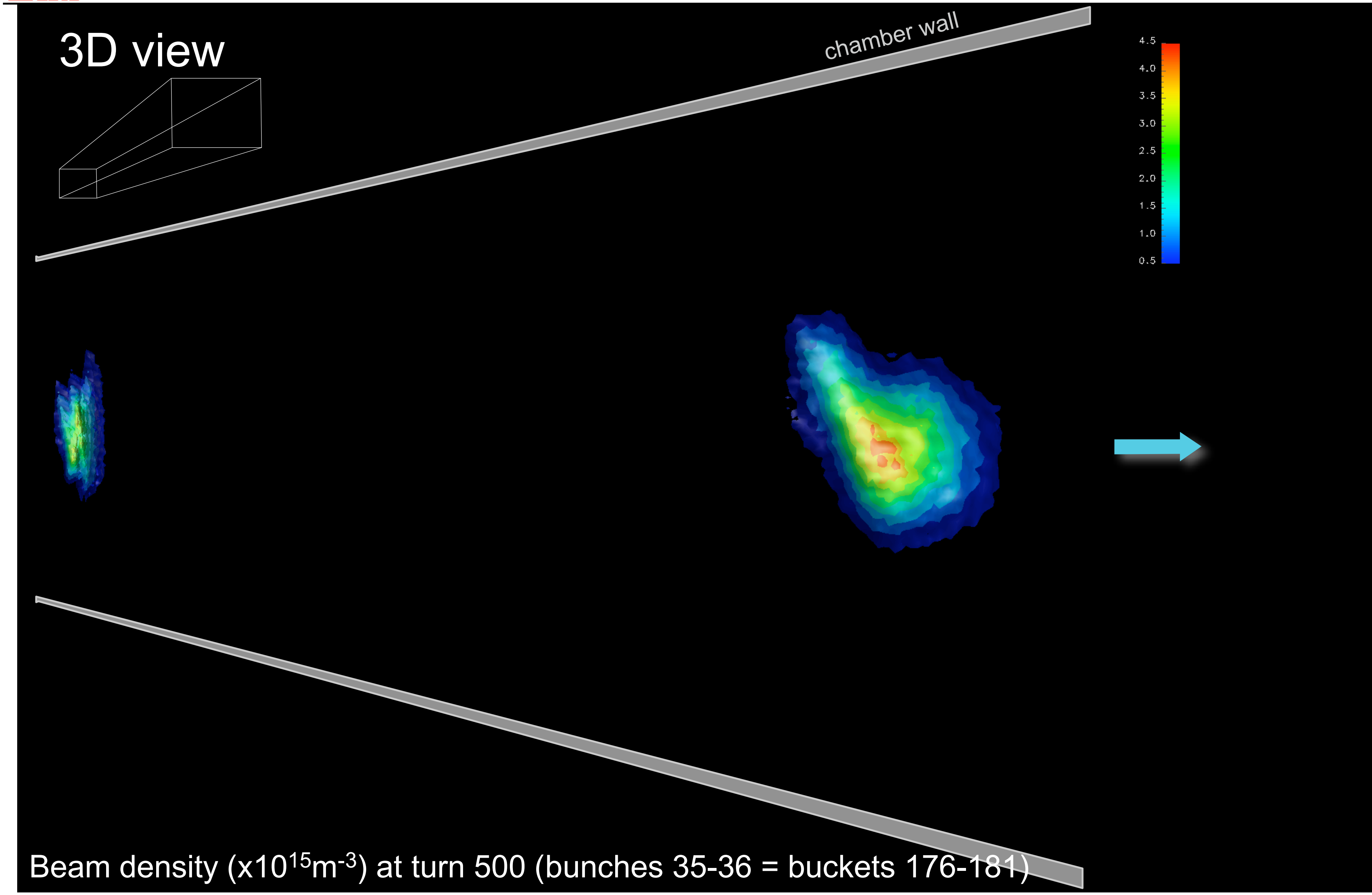
Electron density ($x10^{12}m^{-3}$) at turn 500 (bunches 35-36 = buckets 176-181)

Electrons after 500 turns

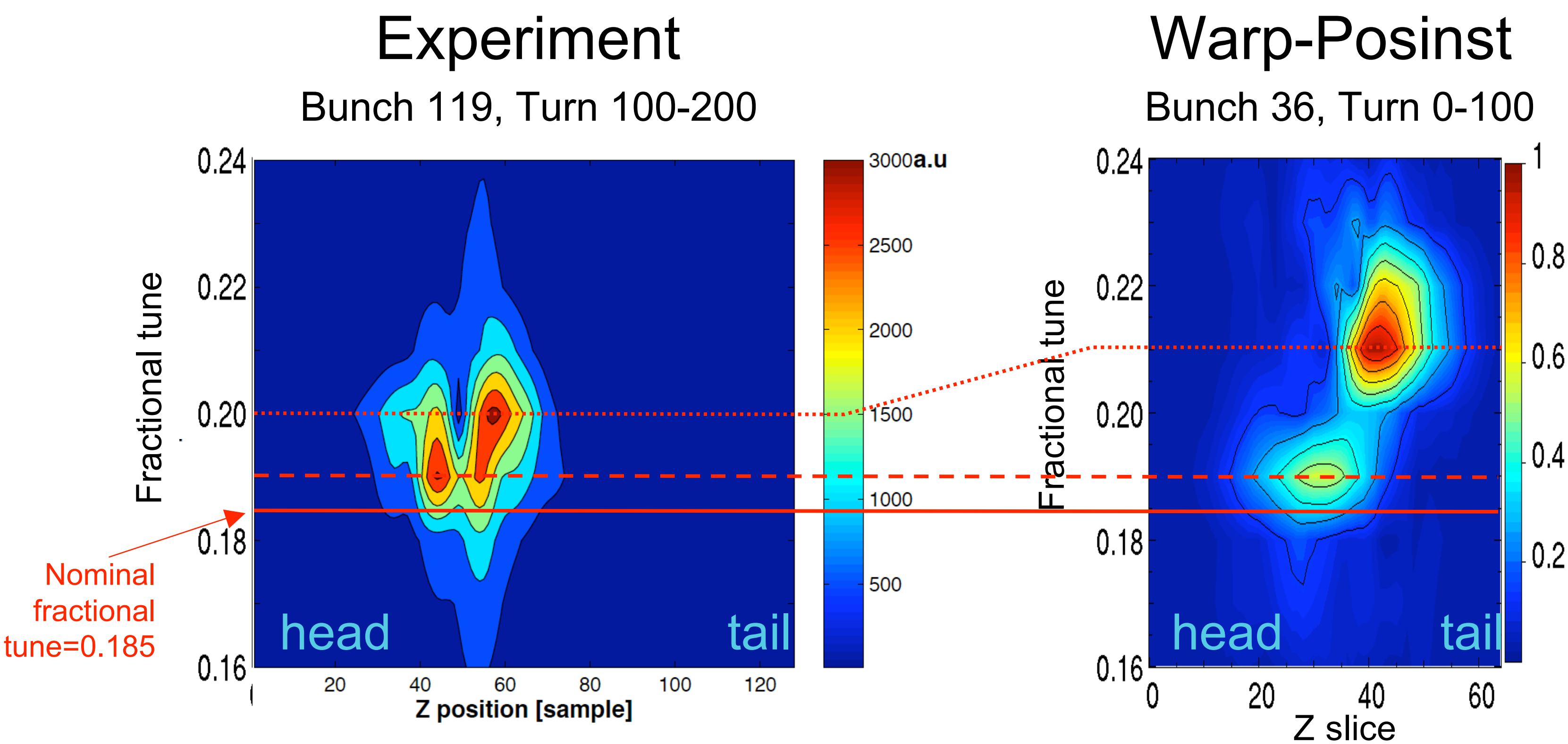


Electron density ($x10^{12}m^{-3}$) at turn 500 (bunches 35-36 = buckets 176-181)

Bunches 35 and 36 after **500** turns



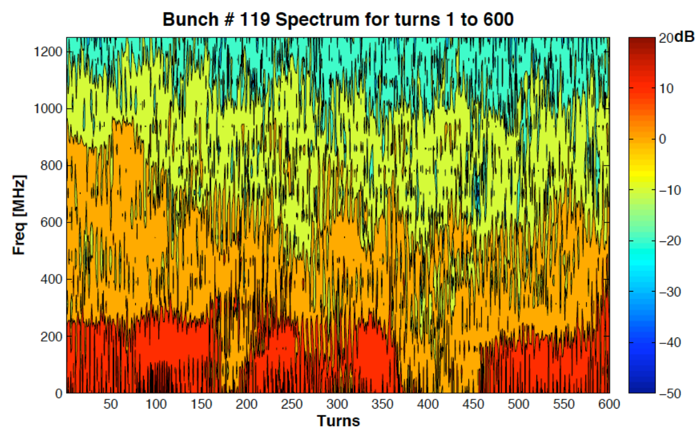
Comparison with experimental measurements



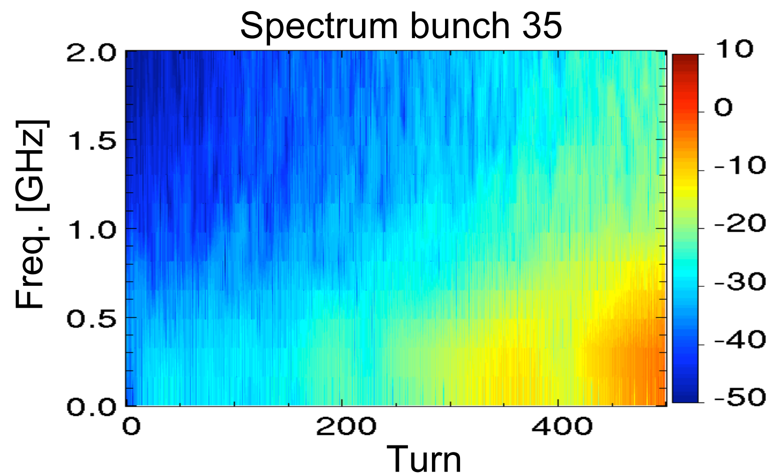
- Separation in two parts, core and tail, with tune shift in tail higher than in core
- Similar tune shift for the core of the beam but higher with simulations for tail
- More experimental results at poster WEPEB052, J. D. Fox et al, “SPS Ecloud instabilities - Analysis of machine studies and implications for ecloud feedback”, Wednesday, May 26, 16:00-18-00.

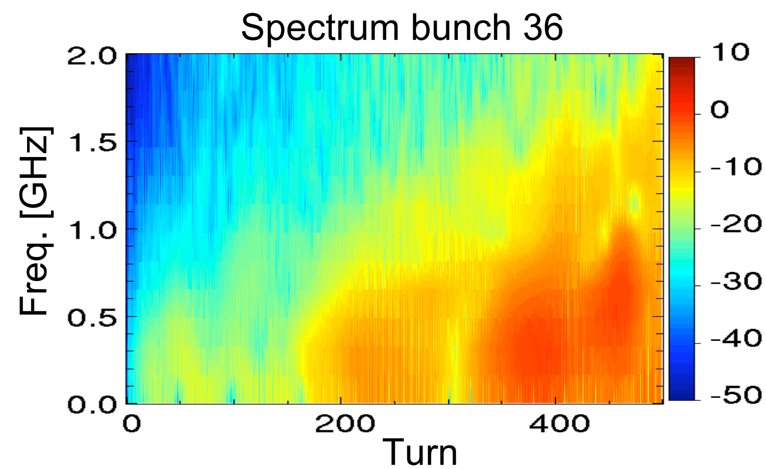
Comparison with experimental measurements - 2

Experiment



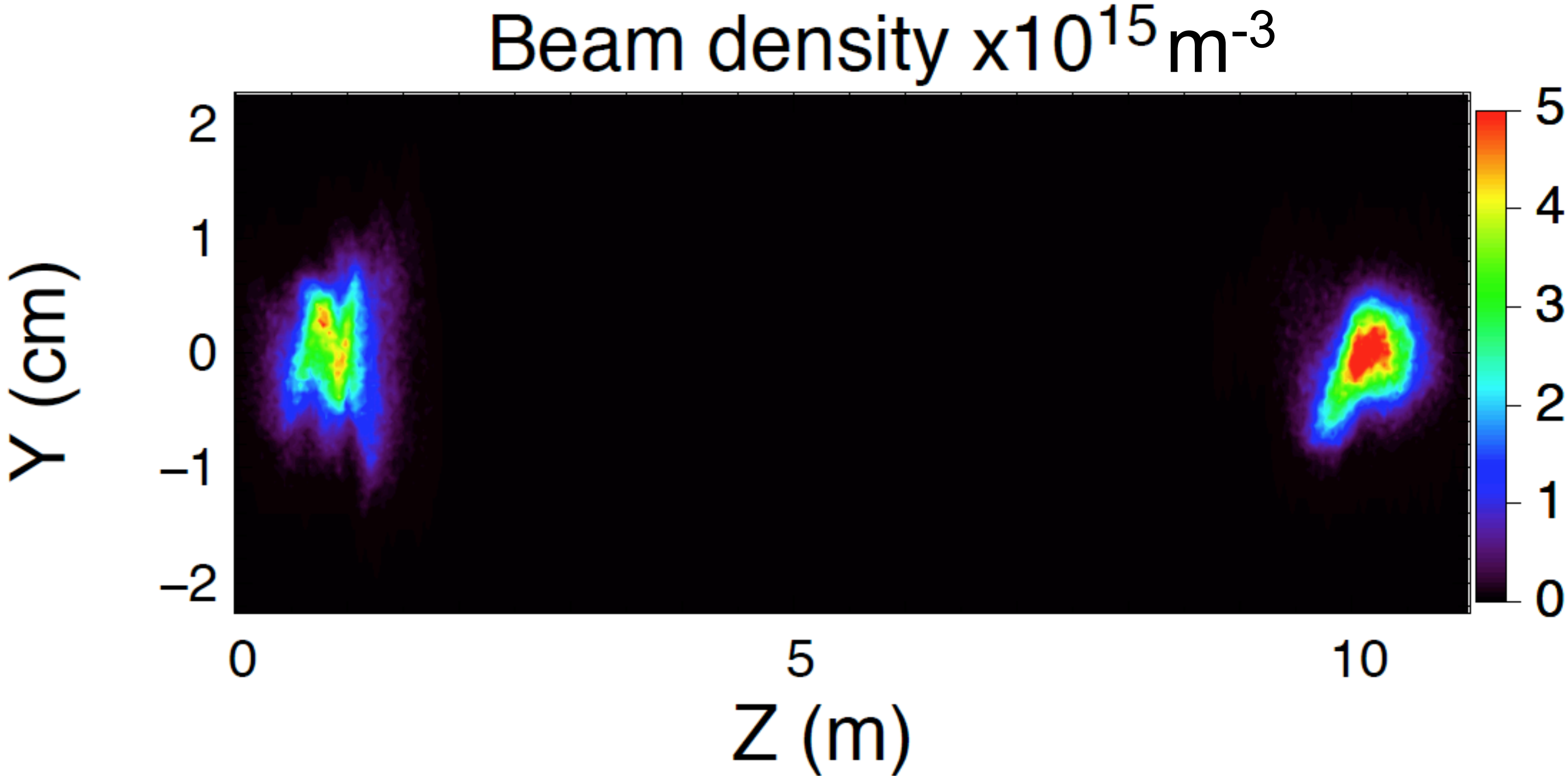
Warp-Posinst





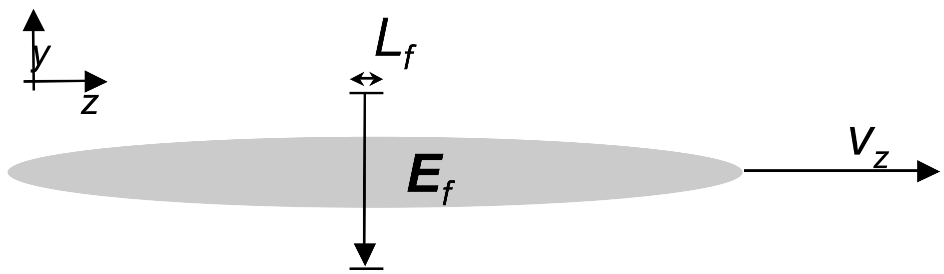
- Both expt. and sim. show activity level inversely proportional to frequency
- Interesting difference: instability grows in simulation but is already there at turn 0 in experiment

Bunches transverse internal structure has fairly long wavelength component



- Can a feedback system resolving the bunch control the instability?
- What characteristics are needed, (amplitude, frequency range, noise level, delay, …)?

Simulated feedback model



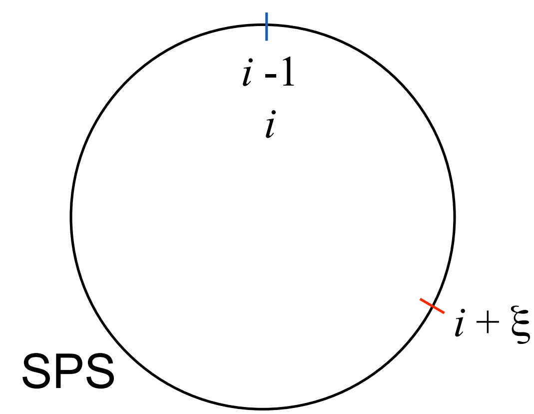
Kick in transverse velocity

$\Delta v_y = (q/\gamma m)\, E_f\, L_f / v_z$

- E_f is set from estimated velocity offset v_y: $E_f = g\, v_y\, (\gamma m/q)\, v_z / L_f \quad (0<g\leq 1)$
- predicts $y'(t)=v_y/v_z$ from records of centroid offsets at two previous turns $y_{i-1}(t)$ and $y_i(t)$ using linear maps, ignoring longitudinal motion and effects from electrons

$$y'_{i+\xi} = \frac{(cc_\xi - ss_\xi)\, y_i - c y_{i-1}}{\beta_y s}$$

with $\begin{cases} c = \cos(2\pi Q_y) & c_\xi = \cos(2\pi \xi Q_y) \\ s = \sin(2\pi Q_y) & s_\xi = \sin(2\pi \xi Q_y) \end{cases}$



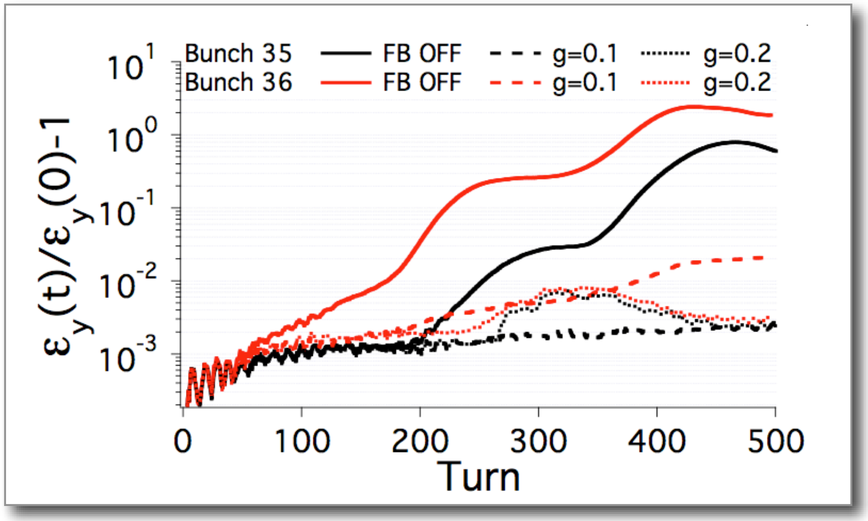
In following results, ξ=1.

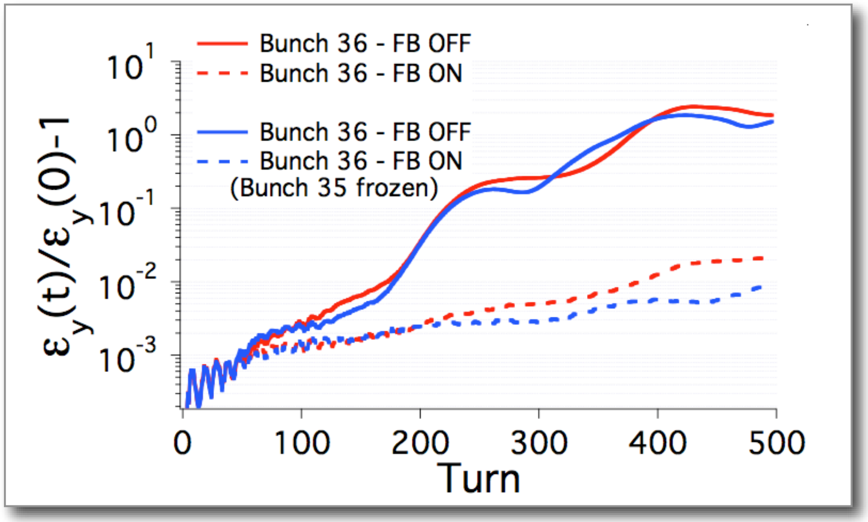
(for ξ=0, same as Byrd PAC95 and Thompson et PAC09)

Emittance history with feedback on/off, with gains g=0.1 and 0.2

Feedback very effective at damping instability.

Better with g=0.2 for bunch 36.



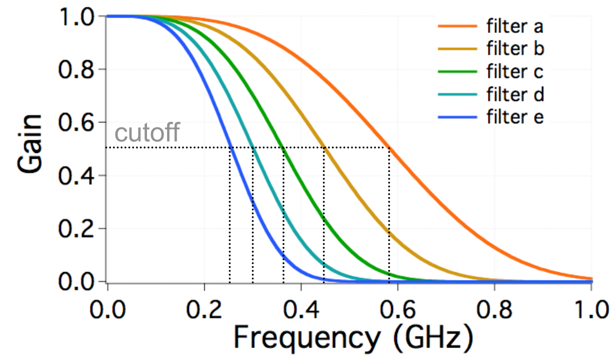


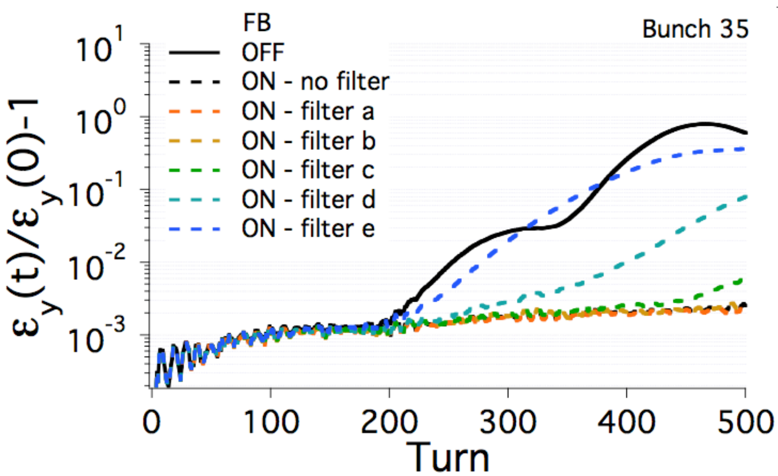
Run with bunch 35 frozen.

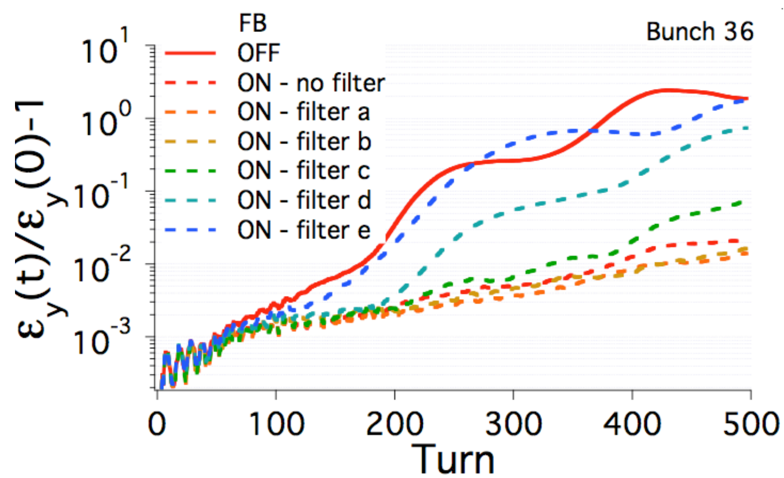
Effect of bunch 35 on 36 is weak.

Tests with finite bandwidth

Runs with 5 different digital filters with cutoffs (-3 dB) around 250, 300, 350, 450 and 575 MHZ.



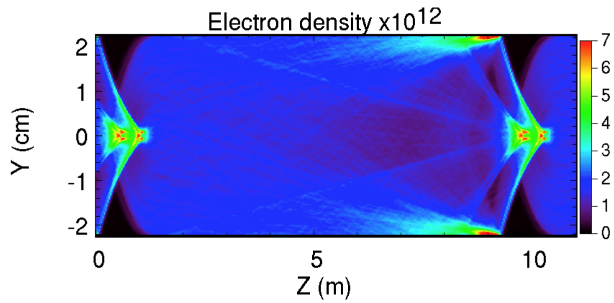


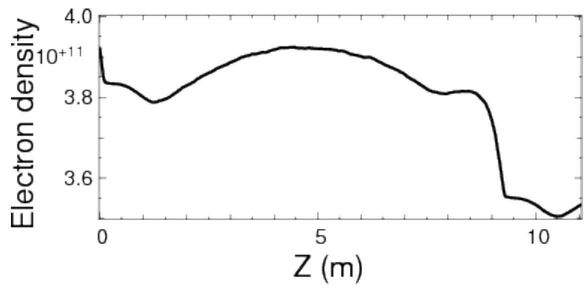


With these filters, cutoff>450 MHz needed for maximum damping.

Multi-bunch simulations: beware of electron injection procedure.

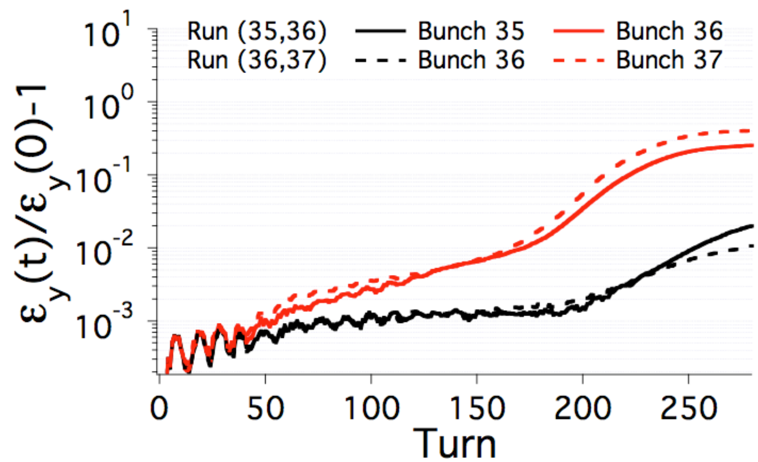
Why is emittance of 36 >> 35?



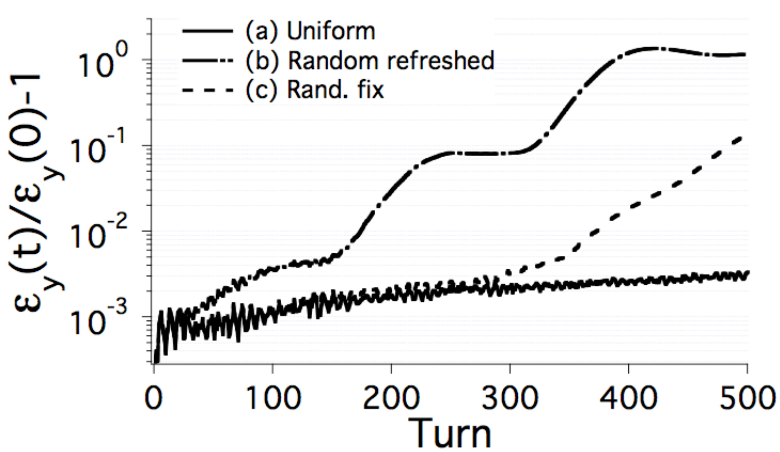


Is it because <n_e> raises by ~8%?

Run of bunch (36,37) gives same emittance histories as (35,36).



Source of inconsistency?



Single bunch runs with electron load
(a) Uniform
(b) Random refreshed at each time step
(c) Random using load from t=0

=> Bunch 36 experienced more noise than 35 because of random secondary electron generation.

Summary and future work

- Beam-ecloud self-consistent simulations are now within reach, allowing detailed understanding of the dynamics and control of beam instability via feedback systems.
- Improvements to Warp-Posinst quasistatic model
  - mesh refinement,
  - secondary emission, gas ionization,
  - better feedback model.
- Multi-bunch simulations are now possible (thanks in part to parallelism).
- Good qualitative and semi-quantitative agreement with experiment.
- Modeling of bunches 35 and 36 in SPS at 26 GeV show effective damping from simulated feedback, provided that bandwidth cutoff>450 MHz.
- Care must be exercised with interpretation due to statistical implications of electrons injection procedures.
- A lot more work is needed, including: implementation of planed feedback n-tag prediction, filtering, etc; better control of numerical noise issue in simulations, eventually using as proxy to emulate real machine noise; replace smooth focusing with linear optics, etc.